AVIATION
MAINTENANCE MANAGEMENT

SECOND EDITION

HARRY A. KINNISON

TARIQ SIDDIQUI

Aviation Maintenance Management

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Harry A. Kinnison

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In memory of Najma Begum Siddiqui

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Preface

I started teaching at Embry Riddle approximately 5 years ago. One of the classes that I have taught all these years is Aircraft Maintenance Management. I started using this book for my class. This is the best textbook for the class. It provides the best insights and knowledge about airline management that are available. However, since the publication of the first edition, the airline industry has gone through drastic changes, reorganizations, and adjustments in fleet size and management. There were various changes in the FAA's advisory circulars and methods of compliance. Due to these changes, I humbly presented to the publishers the idea of revamping the book and creating an even better textbook for the aviation student and faculty.

The result is a combination of the original textbook by Harry A. Kinnison, Ph.D., and my amendments. The purpose of this textbook is to provide insight and perspective to the aviation student on the aviation industry, airline management, aircraft maintenance fundamentals, maintenance planning, FAA regulations, development of maintenance programs, aviation safety, and the steps needed to help improve them.

I would like to thank my professors at Embry Riddle Aeronautical University for their encouragement and support; especially former director of academic support (DAS), Leo Haigley, of the Miami campus. The Pan Am airline family taught me that the airline industry is both beautiful and heartbreaking. I also thank my family for their love and support.

TARIQ SIDDIQUI
Miami Lakes, Florida

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Preface to the First Edition

I never read the "begat chapters" in the front of books until I became a writer myself. I wanted to see just what it took to write a book and was quite surprised to say the least. Although only one name appears on the book as "author" it takes many, many people (as well as numerous books, articles, and experiences) to produce the final, usable manuscript. This textbook is no exception.

The project began many years ago when the author was in Electronics School at Keesler Air Force Base, Mississippi, where instructors have long since become nameless and faceless, but their efforts were not in vain. They planted the seeds for my future harvest. Next, I spent several years as an Airborne Navigation Equipment Repairman in Wiesbaden, Germany. Line, hangar, and shop maintenance activities were drilled into me by a Sergeant Gottlieb R. Schneider, who taught me the art and science of troubleshooting as well. My coworkers—Ron Wright, Tom Cummins, and Gene Hackett—helped immensely in my training. They taught me radar systems and I taught them navigation systems. We all gained from that.

After receiving a Bachelor of Science degree in Electrical Engineering, I spent several years on an Air Force Radar Site as a maintenance officer. Then it was on to civilian employment with the FAA and The Boeing Company. It was the latter experience—about 20 years worth—where I encountered the regulatory, management, and administrative aspects of the maintenance field. The people I worked with, and there were many, all contributed something to my knowledge and understanding of the maintenance field, which I have set forth in this book. Those most directly involved with my education at that level were Isaac Zere, Lloyd Wilson, and Lee McEachron, team leaders on many of my visits to airlines. Others who contributed in various ways were

Peter Ansdell	Naseem Mahmood
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Special thanks should go to those at Embry-Riddle Aeronautical University (ERAU) Extended Campus. They not only hired me to teach the subject of this book, they allowed me to use my own materials. This book is an outgrowth of that original series of lectures. In addition, the staff at the Seattle Center of ERAU not only provided assistance on contacts and information when needed, several of them read and critiqued the manuscript. These people include Dr. Richard Glover, Center Director of Operations; Tom Glover, Center Faculty Chair and Safety Professor; and Dr. Ernie Damier, National Faculty Advisor, ERAU who read the manuscript not once but twice. And last but not least, Terry Cobb, Course Monitor for the Aviation Maintenance Management course for the entire Extended Campus. Their comments and suggestions were quite helpful.

Several airline people have also assisted in this endeavor. First are the employees of foreign and domestic airlines—too numerous to mention by name—who were the key figures of my airline technical visits which addressed various maintenance management topics. Special recognition goes to Dr. Karl Pape, Maintenance Supervisor at United Airlines, retired, now Associate Regional Academic Dean, ERAU Western Region, who read the first draft of the manuscript and provided much information and guidance. Thanks, also, to Les Ross, Aircraft Maintenance Supervisor, United Parcel Service, Ontario, California, for taking the time to discuss his organization's operation with me and for allowing me to measure the inside of one of his package freighters.

Additional information and discussion came from the Air Transport Association (ATA) of America: Victoria Day, Director, Publications and Technical Communications, and Rick Anderson, Director of Maintenance and Material. At the FAA, Northwest Region, Tom Newcomb, Aircraft Evaluation Group (AEG) and Kevin Mullin, Manufacturing Inspection District Office (MIDO), provided copies of FAA certificates to use as illustrations. The Boeing Company's Renton library allowed me to use their facilities for some basic literature research.

As with all such efforts with acknowledgments, this one has probably missed a good many names, and I sincerely want to apologize to those people. It should be understood that their efforts and contributions were just as important and just as appreciated as any of those mentioned.

Although many people have contributed and assisted in the production of this book, it is appropriate that the person whose name appears on the byline should take full credit for any errors or omissions within the text. For those inaccuracies, I humbly apologize.

HARRY A. KINNISON, PH.D.
Kent, Washington

Introduction

Aviation in the Beginning

The 24th International Air Transportation Conference was held in Louisville, Kentucky, June 5–7, 1996. One of the many evening activities available to the attendees was a tour of the main facilities of United Parcel Service (UPS) at the Louisville International Airport. About 15 people signed up for the tour. After watching the young college students hustle around unloading, sorting, and loading the packages and listening to the tour guide's explanation of this unique distribution system, we were escorted out to the flight line parking ramp to look at airplanes. Our tour guide led us up the portable air stairs into the huge chasm that was the Boeing 747 freighter. She stood there for a moment, silently looking around at the huge, empty airframe. Her tour guests did the same. Finally she spoke.

"The cargo area inside this 747 freighter is longer than the Wright brothers' first flight," she said with some pride. "And the deck we are standing on is higher off the ground than that first flight was."[1]

Certainly aviation has come a long way since that windy December day in 1903 when Wilbur and Orville Wright made history at Kill Devil Hills near Kitty Hawk, North Carolina. Likewise, the field of aviation maintenance has made great strides. The early days of aviation were filled with experimenters, daredevils, and showoffs called barnstormers for obvious reasons. With their stunt flying and other antics, they were trying to prove to the public the safety and utility of this newfangled machine, the airplane. Selling "rides" to the curious became a side business. At first, aviation was more entertainment than transportation, but that soon changed. Just as modern jet liners boast dimensions greater than those of the first flight itself, the technological advances in aviation over the ensuing 100 years are equally impressive. And the approach to the maintenance of these complex vehicles has kept pace. Today, aviation is

[1]The Wright Brothers' first flight went 120 ft in about 12 seconds and reached an altitude of less than 10 ft. The Boeing 747 freighter is approximately 150 ft inside and the deck is 16 ft off the ground (unloaded).

the safest mode of transport in the world.[2] A considerable part of that safety record can be attributed to the efforts of mechanics, technicians, engineers, and managers who work in the field of aviation maintenance.

A Brief History of Aviation[3]

Aviation began as a pastime, a sport, a whimsy. Like so many new and "past-the-edge-of-reason" inventions, flying was considered a fanatic's sport. It would not last, people said. It is unnatural. "If God had meant for man to fly He would have given us wings." Well, in a sense He has given us wings.

Through the efforts of people like the Joseph and Jacques Montgofier, Octave Chanute, Otto Lilienthal, Samuel P. Langley, Glenn Curtis, Orville and Wilbur Wright, and many others, we have "earned our wings." We can fly.

All these men devoted time, thought, and fortunes to resolving the problems of manned flight. Even men famous for other great works—Leonardo da Vinci, George Cayley, Hiram Maxim, Thomas Edison, et al.—made contributions. But it was two inquisitive bicycle makers and repairers in Dayton, Ohio, who brought man's longtime longings to "fly like the birds" to fruition. Much work was done by many people, but it was Orville and Wilbur Wright who are credited with the first controlled, manned flight.[4] Although they covered a distance of only 120 feet and got no higher than 10 feet off the ground, their first flight was the result of a concentrated effort to master that which others had only courted.[5] Many experimenters in aviation—some of them with more academic or engineering credentials than the Wrights—had failed to meet the challenge. And some of them, unfortunately, lost their lives in the attempt.

The Wright Brothers were early systems engineers. They insisted that certain obstacles be surmounted, certain ideas be proven regarding manned flight before they would opt to get into their "airplane." An idea other experimenters should have heeded. Although Otto Lilienthal had done considerable work in aerodynamics and had published lift tables for others to use, the Wright Brothers found these tables to be in error and proceeded to make their own corrections. They built a small wind tunnel, made a few tests, and developed their own tables.

---

[2]In 1999, there were 17 commercial aviation deaths for 569 million miles flown. Or 0.003 deaths per 100 million miles. Contrast that with other transportation modes for that same year. Automobile: 20,763 deaths or 0.83 per 100 million miles; railroad: 14 deaths or 0.10 per 100 million miles; transit bus: 1 death or 0.005 per 100 million miles.

[3]Ray Bradbury probably wrote the shortest history of aviation in his short story "Icarus Montgofier Wright." It is recommended reading for aviation students. See Ray Bradbury, "S is for Space," Bantam Books, NY, 1970. Also available in other anthologies.

[4]There were disputes as to who was actually first, but the credit is generally awarded to the Wright Brothers.

[5]The Wright Brothers made four flights in all that first day (December 17, 1903). The fourth one was up for 59 seconds and covered a distance of 852 ft.

Some of the first attempts to fly by the Wright Brothers involved essentially flying a kite.[6] They tied ropes to their craft, released it into the high winds of Kitty Hawk Beach and, by tugging on these ropes and thereby twisting the wing surfaces, they assured themselves that this rig, this airplane, could not only fly with the wind strategically directed over and under its wings, but its direction of flight could be altered and controlled by a human operator. Then and only then would they climb into the contraption themselves. Satisfied that they could control their glider, Orville and Wilbur Wright set out to find an engine with the right power-to-weight ratio to successfully power their invention. They soon found that there was no such engine available, so they designed their own with optimum specifications for flight.[7]

Next, the brothers needed a propeller. They thought the ship-building industry would be the most likely place to solve this problem, but they were disappointed. The shipbuilders told them that, for the most part, props were designed on a trial and error basis—there was no exact science. Undaunted by this, the Wrights designed and built their own propeller. They did not have time to use the trial and error method to develop a suitable propeller, so the Wrights used their newly developed aerodynamic tables to design the ideal device. And they were successful.

Although many others over the next few years after 1903 would make great advances in aviation and improve the performance, safety, and convenience of manned flight, it was the Wright Brothers' systematic process, their effort to design the whole system as a usable device (usable by people), that made the airplane a viable and important invention. The next step would be to convince the public of its value.

Promotion of Flying

Flying was for daredevils, at first. Numerous pilots showed off their skills and their new toys by performing for crowds—acrobatic stunts and other daring maneuvers—and often by selling joy rides to brave onlookers at three to five dollars apiece. But this showmanship soon gave way to those who wanted to see a more practical use for the airplane, and delivery of the U.S. Mail was considered the first down-to-earth application.

The first airline in the United States to carry passengers on a regular schedule was the St. Petersburg to Tampa Airboat Line, which started operations in January 1914 between the two cities, but they carried only one passenger at a time. Service ended after 3 months, however, due to the end of the tourist season and the onset of World War I.

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[6]To this day, old-timers in the Seattle area refer to The Boeing Company as "The Kite Factory."

[7]The Wrights had already designed and built a gasoline engine to run the drill press and lathe in their shop.

After World War I, airmail service began and dominated the aviation industry (such as it was). Entrepreneurs set up airline operations for that specific purpose. Occasionally, a passenger would ride along, sitting atop the mailbags if there was room. But later, additional seats were added to airplanes and passengers became more frequent sources of revenue. The U.S. government encouraged operators to use bigger planes and carry more passengers so they wouldn't have to rely solely on government mail contracts to stay in business.

Navigational aids were nonexistent in the early days of flying, and flyers used railroads, highways, and common automobile road maps to find their way. Nor could the first flyers fly at night until someone decided to light bonfires along the desired route to show the way. Weather conditions were received by observation and by telephone until air-to-ground radio came into use in the late 1920s. By the end of 1929, however, there were over 10,000 miles of lighted airways, 275 lighted airports, and 1352 rotating beacons.

While development of air travel in the United States lagged behind that of Europe after World War I, the opposite was true after World War II. Airplanes got bigger and flew "higher, faster, farther," and in 1958, we were introduced to the "jet age" with the Boeing 707, followed by the Douglas DC-8, and the Lockheed L1011. Navigational aids both on the ground and in the aircraft (later in earth-orbiting satellites) revolutionized the industry along with drastic improvements in aircraft and engine technology. Today, 100 years after the Wright Brothers' historic first flight, aviation has come of age. People can fly—and in immense comfort and safety.

Early Aviation Maintenance

In those early days of aviation, maintenance was performed "as necessary" and the machines often required several hours of maintenance time for every hour of flying time. Major maintenance activities consisted of overhauling nearly everything on the aircraft on a periodic basis. Even though the airplanes and their systems were quite simple at first, maintenance carried out in this manner became quite expensive. With the increasing complexity of the aircraft and their onboard systems over the following years, that expense rose accordingly.

The modern approach to maintenance is more sophisticated. The aircraft are designed for safety, airworthiness, and maintainability, and a detailed maintenance program is developed along with every new model aircraft or derivative of an existing model. This initial maintenance program can then be tailored by each airline to accommodate the nature of their individual operations. This ensures continued airworthy operation under any circumstances. Backing up that individual undertaking are the ongoing efforts by manufacturers, airlines, and regulators to improve design and maintenance techniques and to keep the aviation industry on the leading edge.

Of course, such a sophisticated approach to maintenance requires sophisticated management, both in development of the initial maintenance program

and at the airlines to accomplish all that is necessary to maintain that superior record of safety mentioned earlier.

Technical Management

It takes several disciplines to properly conduct the maintenance activities at an airline: (*a*) Maintenance: the hands-on, "nuts and bolts" labor required to accomplish the physical work; (*b*) Engineering: the design, analysis, and technical assistance required to support maintenance work; (*c*) Management: the organization, control, and administration of the many facets of the maintenance operation; *(d)* Production Planning: the planning concepts and organization activity to support maintenance effectively to plan all required work; (*e*) Logistics: understanding the aircraft inventory scope, realistic, futuristic, to meet the continuous demand for parts required for a successful maintenance operation; (*f*) Technical Training: to meet the demands of all required maintenance training effectively.

This book will be somewhat unique: it will cover all of these topics—maintenance, engineering, management—but in a more cursory manner than the individual courses would address them. We will be looking at the "big picture." We will be looking at maintenance, engineering, and management as an integrated whole. We will examine how all these disciplines combine and coordinate to accomplish the goals and objectives of airline maintenance. While some of the details of these three topics may be left out of the discussion, this text will emphasize the coordination of these three disciplines required to achieve the desired results.

The book is written for those who have background and experience in aviation maintenance and who wish to move into lower and middle level management positions within the airline's maintenance and engineering section. Those managers without a technical background, of course, can still benefit from the book by expanding their horizons to the technical realm. Mechanics and technicians who desire to move into the management of maintenance will gain valuable information about the overall operation of the maintenance and engineering unit.

Aviation Industry Interaction

The aviation industry is unlike any other transportation mode. In aviation, we cannot pull off the road and wait for a tow truck whenever we a have problem. We are required by the Federal Aviation Administration (FAA) regulations to meet all maintenance requirements before releasing a vehicle into service. This is often not the case with other commercial transport modes. In aviation we have a relationship with gravity that differs considerably from that of any other transportation mode. We have problems with extremes of temperature (e.g., very hot engines and very cold air at high altitude).

In aviation we have an interactive group of people determined to make aviation a safe, efficient, and pleasurable activity. Aircraft manufacturers, makers of onboard equipment and systems, airline operators, industry trade associations, regulatory authorities, flight crews, and maintenance personnel all work together to ensure aviation safety from the design of the aircraft and its systems, through the development of maintenance programs and modifications, and continuing throughout the lifetime of the aircraft.

Working together and providing feedback at all levels and in all directions between and among these factions allows the aviation industry to provide continually improved systems and services to the public. The aviation industry was one of the first to employ this "continuous quality improvement" concept even before that catch phrase became popular.

Layout of the Book

This book has five parts. Part I contains information related to the basic philosophy of maintenance, as well as fundamental requirements for an effective maintenance and engineering operation. Part I ends with the discussion of the organizational structure of a typical midsized airline. Parts II through IV give the particulars of each functional unit within that structure. Part V, Appendixes, provides information essential to various aspects of maintenance and engineering activities. These should be read and understood as background or support material for the rest of the book.

Part I: Fundamentals of Maintenance

Chapter 1, Why We Have to Do Maintenance, discusses some basic theory about designing and building complex equipment and why we cannot build perfect systems. This chapter also covers common failure patterns and failure rates of components and systems as well as methods for minimizing service interruptions such as line replaceable units (LRUs), redundant systems, and minimum dispatch requirements (MEL). It establishes the basic reasons why maintenance has to be planned, organized, and systematic.

Chapter 2, Development of Maintenance Programs, discusses the process of creating a maintenance program for a given model aircraft and how that program can be changed by an operator, as necessary, after entry into service. The chapter also defines basic maintenance intervals.

Chapter 3, Definitions, Goals, and Objectives, defines maintenance and a few other selected terms including goals and objectives. The chapter then establishes specific goals and objectives for maintenance. The text discusses how these were developed and what they mean to airline maintenance management.

Chapter 4, Aviation Industry Certification Requirements, addresses the Federal Aviation Administrations requirements for aircraft design and manufacture and the federal requirements with which a transportation company must comply to become an airline and operate the aircraft in commercial service.

Chapter 5, Documentation for Maintenance, discusses the manuals supplied by the manufacturers and vendors with the aircraft, the documentation required to be written by the airline for defining maintenance activities, and the regulations and advisories issued by the Federal Aviation Administration and other regulatory authorities relative to that maintenance.

Chapter 6, Requirements for a Maintenance Program, covers the regulatory requirements for a maintenance program outlined in FAA Advisory Circular, AC-120-16E and other FAA requirements: scheduled and unscheduled maintenance, inspection, overhaul, and recordkeeping. The chapter also discusses additional management requirements deemed necessary by airline managers: requirements for engineering, reliability, quality assurance, computer support, and training, for example.

Chapter 7, The Maintenance and Engineering Organization, covers the organizational structure of the maintenance and engineering function of a typical, midsized airline based on the requirements identified in Chap. 6. Variations of this structure for large and small airlines as well as operators with multiple maintenance bases and those who outsource some or all of the major maintenance work are also discussed.

Part II: Technical Services

Chapter 8, Engineering, covers the duties and responsibilities of the technical experts of the maintenance organization. This includes development of the airline's maintenance program from the airframe manufacturer's data and creation of the policies and procedures that govern the execution of that program. Engineering also provides assistance to maintenance for the solution of difficult problems and performs investigation of maintenance problems noted by the reliability program, as well as problems brought up by mechanics or by personnel from the quality control and quality assurance organization.

Chapter 9, Production Planning and Control, discusses the organization and workings of the department that is at the center of all maintenance activity. Production planning and control (PP&C) is responsible for all maintenance activities performed on the unit's aircraft. Duties and responsibilities of PP&C include forecasting future maintenance requirements and activities, planning and scheduling major checks for the current operational situation, and exercising control of the maintenance in progress. They are responsible for ensuring that personnel, parts, facilities, and special tools and test equipment are available for each planned maintenance event and that the activity is accomplished successfully and on time.

Chapter 10, Technical Publications, discusses the publication and distribution of all documentation required by the various maintenance and engineering departments. This includes documents provided by manufacturers, vendors, and regulatory authorities as well as those documents produced by the airline.

Chapter 11, Technical Training, covers the training requirements of mechanics, technicians, quality control (QC) inspectors, and quality assurance (QA) auditors.

The chapter also discusses training conducted by the airline as well as that done by outside sources. The technical training organization is also required by the FAA to keep records of all training accomplished by each employee.

Part III: Aircraft Management, Maintenance, and Material Support

Chapter 12 will show the aircraft maintenance management, structure, role of management in aviation, coordinated activities, front line management their responsibilities, upkeep of industry trends, new development in aviation management, and management concerns in aircraft maintenance.

Chapter 13, Line Maintenance (on-Aircraft), discusses the activities of the line maintenance units that are responsible for maintenance and servicing on all aircraft in service. This includes maintenance activities at the home base, at outstations where the airline performs regular stops, and the organization and operation of a maintenance control center, the unit responsible for coordinating maintenance for all in-service aircraft.

Chapter 14, Hangar Maintenance (on-Aircraft), discusses the unit that is involved with maintenance activity on out-of-service aircraft (i.e., aircraft not currently on the flight schedule). The hangar group handles all major maintenance activities including major modifications. Both line and hangar maintenance are supported by the ground support equipment (GSE) unit that provides power units, work stands, and various other equipment and facilities for the efficient production of maintenance and servicing. Maintenance Overhaul Shops (off-Aircraft) discusses the organizations that perform maintenance on systems and components that have been removed from the aircraft during line or hangar maintenance activities. These shops are sometimes called back shops, and include avionics, mechanical, and hydraulic systems and various other specialty shops. They may also include third-party maintenance activities. The organizations of these shops as well as their work and data collection efforts are discussed.

Chapter 15, Material Support, discusses the functions and processes of purchasing, issuing, inventory control, loaner and bogus parts, and storing parts and supplies needed for the maintenance operation. Material establishes usage rates and reorder points to ensure adequate stock is on hand at all times. Material is also responsible for processing defective units through maintenance and for handling warranty claims on equipment.

Part IV: Oversight Functions

Chapter 16, Quality Assurance, covers one of the primary oversight functions an airline needs to ensure top operation. Quality assurance (QA) is responsible for setting maintenance standards at the airline and also serves as M&E's point of contact with the regulatory authority. QA also performs yearly audits of all maintenance and engineering functions, including outside suppliers and contractors, to ensure compliance with airline and regulatory requirements.

Chapter 17, Quality Control, discusses the duties and responsibilities of those inspectors who provide direct oversight of the performance of maintenance actions. While QA looks at the overall compliance to rules and regulations, QC looks at the day-to-day work activities for compliance with good maintenance practices and procedures. The QC organization is also responsible for conducting nondestructive test and inspection activities and for the calibration of tools and test equipment.

Chapter 18, Reliability, discusses types of reliability and the concept of a reliability program to monitor the effectiveness of the airline's maintenance activity. Data collection on maintenance actions, such as failures, removals, etc., is monitored for trends. Investigation is made into possible problem areas so that corrective action can be implemented. Follow-up activities of reliability determine the effectiveness of that corrective action and the need (if any) for further action.

Chapter 19, Maintenance Safety, discusses the safety programs of the airline as they relate to maintenance and engineering. This includes smoking regulations, fire detection and prevention, fall protection, handling of hazardous material, etc. The chapter also discusses the material safety data sheets (MSDS) and the "right to know" program to alert workers to hazards.

Part V: Appendixes

Appendix A, Systems Engineering, discusses the concept of systems engineering and how it applies to maintenance and engineering in aviation. The text includes discussion of various system engineering terms, such as internal and external components, inputs and outputs, system boundaries, and the changing of system boundaries for the sake of analysis. It also discusses the difference between the systems approach and the systematic approach.

Appendix B, Human Factors in Maintenance, discusses the application of human factors in the maintenance field. Since human beings constantly interface with the complex aviation equipment, those humans should be considered as part of the system when it is designed. This appendix discusses human factors in general and then discusses human factors as they relate to systems engineering. The appendix ends with a discussion of human factors activities at the manufacturer and airline levels.

Appendix C, The Art and Science of Troubleshooting, discusses one of the fundamentals of a maintenance activity that is difficult and elusive. Troubleshooting requires a certain amount of experience for one to blossom fully in the art, but there are some basic concepts one should understand first. This appendix provides the fundamentals of the troubleshooting process, which can be used by maintenance mechanics and technicians, by engineering personnel, and by management to locate and pinpoint problems.

Appendix D, Investigation of Reliability Alerts, provides detailed information on how engineering would go about investigating maintenance problems identified by the reliability program. It is an extension of the troubleshooting process.

While mechanics look at a specific system and its interfacing equipment, the engineer must look beyond the particular electrical, electronic, or mechanical system and include the entire aviation environment, if necessary, in his or her analysis of a problem. This appendix consists of a cross-functional chart showing the interaction of M&E organizations during the process of these investigations and a series of flow charts to guide the investigator through the process of determining the specific problem area.

Appendix E, Extended Range Operations (ETOPS), discusses the 60-minute rule for two-engine airplanes (FAR 121.161) and provides some historical background on the development of ETOPS. Requirements a carrier must meet to obtain FAA permission to deviate from the 60-minute rule (i.e., to fly ETOPS) are also covered.

Appendix F, Glossary, is a list of terms and abbreviations used throughout the book.

Part

Fundamentals of Maintenance

"... maintenance is a science since its execution relies, sooner or later, on most or all of the sciences. It is an art because seemingly identical problems regularly demand and receive varying approaches and actions and because some managers, foremen, and mechanics display greater aptitude for it than others show or even attain. It is above all a philosophy because it is a discipline that can be applied intensively, modestly, or not at all, depending upon a wide range of variables that frequently transcend more immediate and obvious solutions."

LINDLEY R. HIGGINS
Maintenance Engineering Handbook; McGraw-Hill, NY, 1990.

These opening chapters contain basic information related to the aviation maintenance field and should be considered background for the maintenance management effort. Chapter 1 begins with a discussion of the fundamental reasons why we have to do maintenance in the first place. After all, our skills and techniques have improved immensely over the 100-year history of flight, but we haven't quite reached total perfection. And, considering the number of components on a modern aircraft, we realize early on that maintenance is a complex, ongoing process. For that reason, we need to approach it systematically.

We need a well-thought-out program to address the diverse activities we will encounter in this endeavor, so in Chap. 2 we will study the industry procedures for developing an initial maintenance program. We will discuss the various maintenance check packages (the 48-hour and transit check, the monthly "A" check, the yearly "C" check, etc.)

used to implement the maintenance tasks. We then address the ongoing process of adjusting that program during the lifetime of the equipment. In Chap. 3, we establish the goals and objectives for an airline maintenance program that will serve the real-life operation.

Chapter 4 discusses the extensive certification requirements levied on the aviation industry from the original design of the vehicle to the establishment of commercial operators and the people who run them. The documentation for the aircraft, its operation, and its maintenance, is discussed in Chap. 5 and includes the documents produced by the equipment manufacturers, by the regulatory authorities, and by the airline itself.

Chapter 6 will identify those activities required by the FAA to accomplish maintenance as well as those additional requirements deemed necessary by operators to coordinate and implement an effective maintenance and engineering program. Chapter 7 defines a maintenance and engineering (M&E) organization for a typical midsized airline. Variations for larger and smaller airlines will also be discussed. Part I, then, can serve as background to the remainder of the book and can, if desired, be used as the basis for a first or introductory course on the subject of aviation maintenance management.

Chapter

1

Why We Have to Do Maintenance

Introduction

Why do we have to do maintenance? It is simple: "The maintenance of an aircraft provides assurance of flight safety, reliability, and airworthiness." The aircraft maintenance department is responsible for accomplishing all maintenance tasks as per the aircraft manufacturer and the company's requirements. The goal is a safe, reliable, and airworthy aircraft.

The aircraft maintenance department provides maintenance and preventive maintenance to ensure reliability, which translates into aircraft availability. These functions do not preclude a random failure or degradation of any part or system, but routine maintenance and checks will keep these from happening and keep the aircraft in good flying condition.

Thermodynamics Revisited

Nearly all engineering students have to take a course in thermodynamics in their undergraduate years. To some students, aerodynamicists and power plant engineers for example, thermodynamics is a major requirement for graduation. Others, such as electrical engineers for instance, take the course as a necessary requirement for graduation. Of course, thermodynamics and numerous other courses are "required" for all engineers because these courses apply to the various theories of science and engineering that must be understood to effectively apply the "college learning" to the real world. After all, that is what engineering is all about—bridging the gap between theory and reality.

There is one concept in thermodynamics that often puzzles students. That concept is labeled *entropy*. The academic experts in the thermodynamics field got together one day (as one thermo professor explained) to create a classical thermodynamic equation describing all the energy of a system—any system. When they finished, they had an equation of more than several terms; and all

but one of these terms were easily explainable. They identified the terms for heat energy, potential energy, kinetic energy, etc., but one term remained. They were puzzled about the meaning of this term. They knew they had done the work correctly; the term had to represent energy. So, after considerable pondering by these experts, the mysterious term was dubbed "unavailable energy"—energy that is unavailable for use. This explanation satisfied the basic law of thermodynamics that energy can neither be created nor destroyed; it can only be transformed. And it helped to validate their equation.

Let us shed a little more light on this. Energy is applied to create a system by manipulating, processing, and organizing various elements of the universe. More energy is applied to make the system do its prescribed job. And whenever the system is operated, the sum total of its output energy is less than the total energy input. While some of this can be attributed to heat loss through friction and other similar, traceable actions, there is still an imbalance of energy. Defining entropy as the "unavailable energy" of a system rectifies that imbalance.

The late Dr. Isaac Asimov, biophysicist and prolific writer of science fact and science fiction,[1] had the unique ability to explain the most difficult science to the layperson in simple, understandable terms. Dr. Asimov says that if you want to understand the concept of entropy in practical terms, think of it as the difference between the theoretically perfect system you have on the drawing board and the actual, physical system you have in hand. In other words, we can design perfect systems on paper, but we cannot build perfect systems in the real world. The difference between that which we design and that which we can build constitutes the natural entropy of the system.

A Saw Blade Has Width

This concept of entropy, or unavailable energy, can be illustrated by a simple example. Mathematically, it is possible to take a half of a number repeatedly forever. That is, half of one is 1/2; half of that is 1/4, half of that is 1/8, and so on to infinity. Although the resulting number is smaller and smaller each time you divide, you can continue the process as long as you can stand to do so, and you will never reach the end.

Now, take a piece of wood about 2 feet long (a 2 × 4 will do) and a crosscut saw. Cut the board in half (on the short dimension). Then take one of the pieces and cut that in half. You can continue this until you reach a point where you can no longer hold the board to saw it. But, even if you could find some way to hold it while you sawed, you would soon reach a point where the piece you have left to cut is thinner than the saw blade itself. When (if) you saw it one more time, there will be nothing left at all—nothing but the pile of sawdust on the floor. The number of cuts made will be far less than the infinite number of times that you divided the number by two in theory.

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[1] Dr. Asimov wrote over 400 books during his lifetime.

The fact that the saw blade has width and that the act of sawing creates a kerf in the wood wider than the saw blade itself, constitutes the entropy of this system. And no matter how thin you make the saw blade, the fact that it has width will limit the number of cuts that can be made. Even a laser beam has width. This is a rather simple example, but you can see that the real world is not the same as the theoretical one that scientists and some engineers live in. Nothing is perfect.

The Role of the Engineer

The design of systems or components is not only limited by the imperfections of the physical world (i.e., the "natural entropy" of the system), it is also limited by a number of other constraints which we could refer to as "man-made entropy." A design engineer may be limited from making the perfect design by the technology or the state of the art within any facet of the design effort. He or she may be limited by ability or technique; or, more often than not, the designer may be limited by economics; i.e., there just is not enough money to build that nearly perfect system that is on the drawing board or in the designer's mind. Although the designer is limited by many factors, in the tradition of good engineering practice, the designer is obliged to build the best system possible within the constraints given.

Another common situation in design occurs when the designer has produced what he or she believes is the optimum system when the boss, who is responsible for budget asks, "How much will it cost to build this?" The designer has meticulously calculated that these widgets can be mass produced for $1200 each. "Great," says the boss. "Now redesign it so we can build it for under a thousand dollars." That means redesign, usually with reduced tolerances, cheaper materials, and, unfortunately, more entropy. More entropy sometimes translates into more maintenance required. The design engineer's primary concern, then, is to minimize (not eliminate) the entropy of the system he or she is designing while staying within the required constraints.

The Role of the Mechanic

The mechanic [aircraft maintenance technician (AMT), repairer, or maintainer], on the other hand, has a different problem. Let us, once again, refer to the field of thermodynamics. One important point to understand is that entropy not only exists in every system, but that the entropy of a system is always increasing. That means that the designed-in level of perfection (imperfection?) will not be permanent. Some components or systems will deteriorate from use, and some will deteriorate from lack of use (time or environment related). Misuse by an operator or user may also cause some premature deterioration or degradation of the system or even outright damage. This deterioration or degradation of the system represents an increase in the total entropy of the system. Therefore, while the engineer's job is to minimize the

entropy of a system during design, the mechanic's job is to combat the natural, continual increase in the entropy of the system during its operational lifetime.

To summarize, it is the engineer's responsibility to design the system with as high degree of perfection (low entropy) as possible within reasonable limits. The mechanic's responsibility is to remove and replace parts, troubleshoot systems, isolate faults in systems by following the fault isolation manual (FIM, discussed in Chap. 5), and restore systems for their intended use.

Two Types of Maintenance

Figure 1-1 is a graph showing the level of perfection of a typical system. One hundred percent perfection is at the very top of the *y*-axis. The *x*-axis depicts time. There are no numbers on the scales on either axis since actual values have no meaning in this theoretical discussion. The left end of the curve shows the level of perfection attained by the designers of our real world system. Note that the curve begins to turn downward with time. This is a representation of the natural increase in entropy of the system—the natural

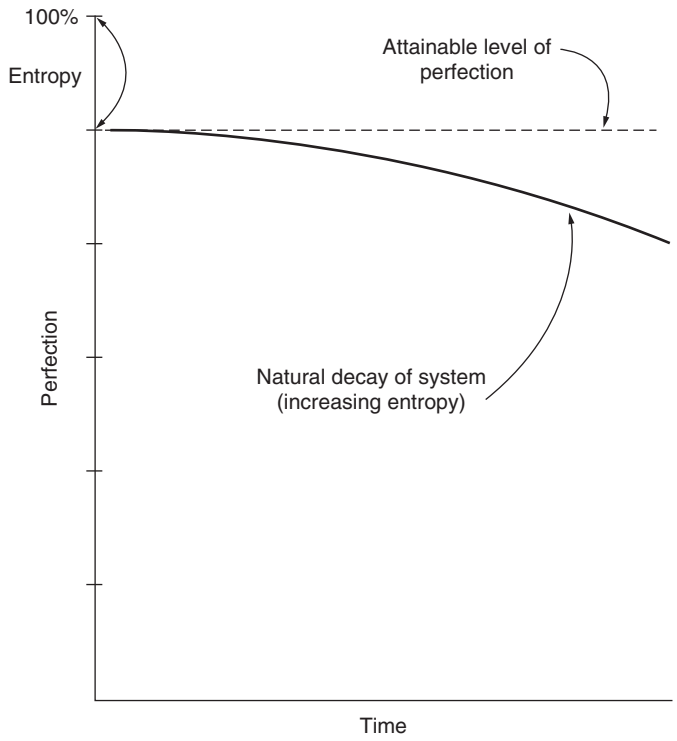


Figure 1-1 The difference between theory and practice.

deterioration of the system—over time. When the system deteriorates to some lower (arbitrarily set) level of perfection, we perform some corrective action: adjusting, tweaking, servicing, or some other form of maintenance to restore the system to its designed-in level of perfection. That is, we reduce the entropy to its original level. This is called *preventive maintenance* and is usually performed at regular intervals. This is done to prevent deterioration of the system to an unusable level and to keep it in operational condition. It is sometimes referred to as *scheduled maintenance*. This schedule could be daily, every flight, every 200 flight hours, or every 100 cycles (a cycle is a takeoff and a landing).

Figure 1-2 shows the system restored to its normal level (curves a and b). There are times, of course, when the system deteriorates rather rapidly in service to a low level of perfection (curve c). At other times the system breaks down completely (curve d). In these cases, the maintenance actions necessary to restore the system are more definitive, often requiring extensive testing, troubleshooting, adjusting, and, very often, the replacement, restoration, or complete overhaul of parts or subsystems. Since these breakdowns occur at various, unpredictable intervals, the maintenance actions employed to correct the problem are referred to as *unscheduled maintenance*.

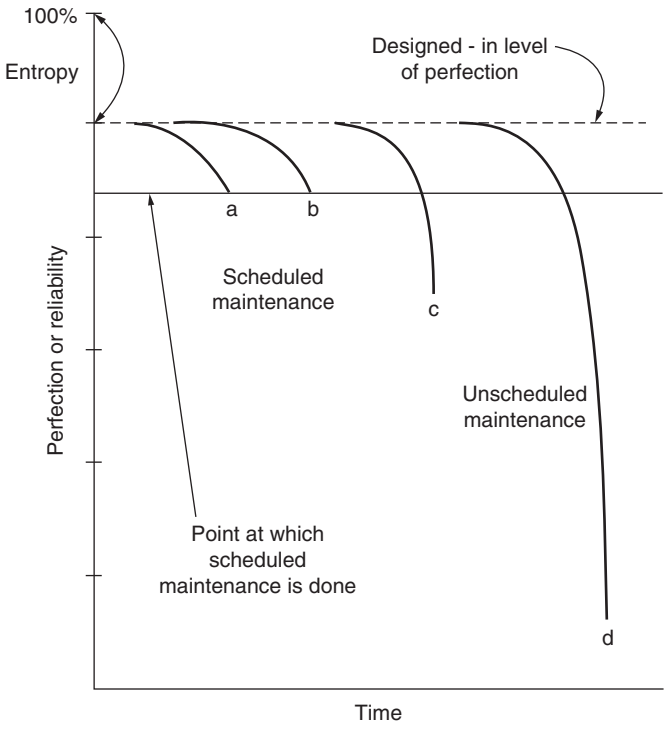


Figure 1-2 Restoration of system perfection.

Reliability

The level of perfection we have been talking about can also be referred to as the reliability of the system. The designed-in level of perfection is known as the inherent reliability of that system. This is as good as the system gets during real world operation. No amount of maintenance can increase system reliability any higher than this inherent level. However, it is desirable for the operator to maintain this level of reliability (or this level of perfection) at all times. We will discuss reliability and maintenance in more detail in Chaps. 13, 14, and 18. But there is one more important point to cover—redesign of the equipment.

Redesign

Figure 1-3 shows the original curve of our theoretical system, curve A. The dashed line shows the system's original level of perfection. Our system, however, has now been redesigned to a higher level of perfection; that is, a higher level of reliability with a corresponding decrease in total entropy. During this redesign, new components, new materials, or new techniques may have been used to reduce the natural entropy of the system. In some cases, a reduction in man-

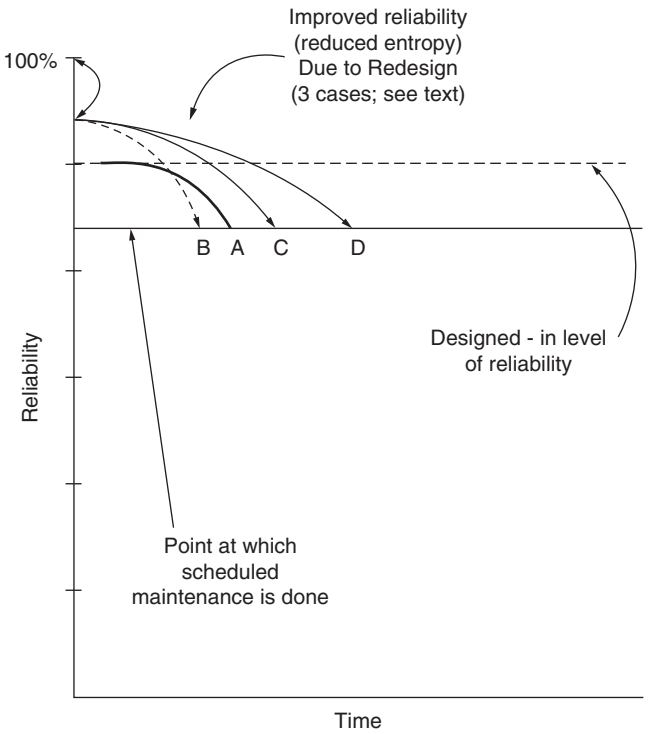


Figure 1-3 Effects of redesign on system reliability.

made entropy may result because the designer applied tighter tolerances, attained improved design skills, or changed the design philosophy.

Although the designers have reduced the entropy of the system, the system will still deteriorate. It is quite possible that the rate of deterioration will change from the original design depending upon numerous factors; thus, the slope of the curve may increase, decrease, or stay the same. Whichever is the case, the maintenance requirements of the system could be affected in some way.

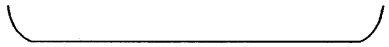
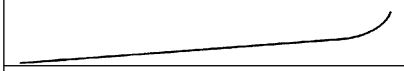
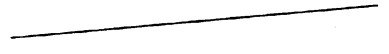
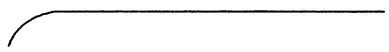
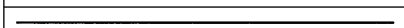
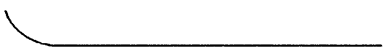
If the decay is steeper, as in (B) in Fig. 1-3, the point at which preventive maintenance needs to be performed might occur sooner, and the interval between subsequent actions would be shorter. The result is that maintenance will be needed more often. In this case, the inherent reliability is increased, but more maintenance is required to maintain that level of reliability (level of perfection). Unless the performance characteristics of the system have been improved, this redesign may not be acceptable. A decision must be made to determine if the performance improvement justifies more maintenance and thus an increase in maintenance costs.

Conversely, if the decay rate is the same as before, as shown in curve C of Fig. 1-3, or less steep, as shown in curve D, then the maintenance interval would be increased and the overall amount of preventive maintenance might be reduced. The question to be considered, then, is this: Does the reduction of maintenance justify the cost of the redesign? This question, of course, is a matter for the designers to ponder, not the maintenance people.

One of the major factors in redesign is cost. Figure 1-4 shows the graphs of two familiar and opposing relationships. The upper curve is logarithmic. It represents the increasing perfection attained with more sophisticated design efforts.

Figure 1-4 Perfection vs. cost.

TABLE 1-1 Failure Rate Patterns

	A. Infant mortality; constant or slightly rising failure rate; definite wear-out period (4%)
	B. No infant mortality; slightly rising failure rate; definite wear-out period (2%)
	C. No infant mortality; slightly rising rate; no definite wear-out period (5%)
	D. Increasing failure rate at outset; constant or slightly rising rate; no definite wear-out period (7%)
	E. No infant mortality; constant failure rate throughout life; no definite wear-out period (14%)
	F. Infant mortality; constant failure rate throughout life; no definite wear-out period (68%)

Source: F. Stanley Nowlan and Howard F. Heap: *Reliability-Centered Maintenance*; U.S. Department of Commerce, National Technical Information Service, Washington, DC, 1978.

The closer we get to perfection (top of the illustration) the harder it is to make a substantial increase. (We will never get to 100 percent.) The lower curve depicts the cost of those ongoing efforts to improve the system. This, unfortunately, is an exponential curve. The more we try to approach perfection, the more it is going to cost us. It is obvious, then, that the designers are limited in their goal of perfection, not just by entropy but also by costs. The combination of these two limitations is basically responsible for our profession of maintenance.

Failure Rate Patterns

Maintenance, of course, is not as simple as one might conclude from the above discussion of entropy. There is one important fact that must be acknowledged: not all systems or components fail at the same rate nor do they all exhibit the same pattern of wear out and failure. As you might expect, the nature of the maintenance performed on these components and systems is related to those failure rates and failure patterns.

United Airlines did some studies on lifetime failure rates and found six basic patterns.[2] These are shown in Table 1-1. The vertical axes show failure rates and the horizontal axes indicate time. No values are shown on the scales since these are not really important to the discussion.

Curve A shows what is commonly referred to as the "bathtub" curve, for obvious reasons. This failure rate pattern exhibits a high rate of failure during the early portion of the component's life, known as infant mortality. This is one of the bugaboos of engineering. Some components exhibit early failures for several

[2]Nowlan, F. Stanley and Howard F. Heap, *Reliability-Centered Maintenance*. National Technical Information Service, Washington, DC, 1978.

reasons: poor design, improper parts, or incorrect usage. Once the bugs are worked out and the equipment settles into its pattern, the failure rate levels off or rises only slightly over time. That is, until the later stages of the component's life. The rapid rise shown in curve A near the end of its life is an indication of wear out. The physical limit of the component's materials has been reached.

Curve B exhibits no infant mortality but shows a level, or slightly rising failure rate characteristic throughout the component's life until a definite wear-out period is exhibited toward the end.

Curve C depicts components with a slightly increasing failure rate with no infant mortality and no discernible wear-out period, but at some point, it becomes unusable.

Curve D shows a low failure rate when new (or just out of the shop), which rises to some steady level and holds throughout most of the component's life.

Curve E is an ideal component: no infant mortality and no wear-out period, just steady (or slightly rising) failure rate throughout its life.

Curve F shows components with an infant mortality followed by a level or slightly rising failure rate and no wear-out period.

The United Airlines study showed that only about 11 percent of the items included in the experiment (those shown in curves A, B, and C of Table 1-1) would benefit from setting operating limits or from applying a repeated check of wear conditions. The other 89 percent would not. Thus, time of failure or deterioration beyond useful levels could be predicted on only 11 percent of the items (curves A, B, and C of Table 1-1). The other 89 percent (depicted by curves D, E, and F of Table 1-1) would require some other approach. The implication of this variation is that the components with definite life limits and/or wear-out periods will benefit from scheduled maintenance. They will not all come due for maintenance or replacement at the same time, however, but they can be scheduled; and the required maintenance activity can be spread out over the available time, thus avoiding peaks and valleys in the workload. The other 89 percent, unfortunately, will have to be operated to failure before replacement or repair is done. This, being unpredictable, would result in the need for maintenance at odd times and at various intervals; i.e., unscheduled maintenance.

These characteristics of failure make it necessary to approach maintenance in a systematic manner, to reduce peak periods of unscheduled maintenance. The industry has taken this into consideration and has employed several techniques in the design and manufacturing of aircraft and systems to accommodate the problem. These are discussed in the next section.

Other Maintenance Considerations

The aviation industry has developed three management techniques for addressing the in-service interruptions created by the items that must be operated to failure before maintenance can be done. These are equipment redundancy, line replaceable units, and minimum aircraft dispatch requirements.

The concept of redundancy of certain components or systems is quite common in engineering design of systems where a high reliability is desirable. In the case of redundant units—usually called primary and backup units—if one unit fails, the other is available to take over the function. For example, in aviation most commercial jets have two high-frequency (HF) radios. Only one is needed for communications, but the second one is there for backup in case the first one fails.

A unique feature of redundant units also affects the maintenance requirements. If both primary and backup units are instrumented such that the flight crew is aware of any malfunction, no prior maintenance check is required to indicate that incapability. On the other hand, if neither system is so instrumented, maintenance personnel would need to perform some check on both primary and backup systems (at the transit or other check) to determine serviceability.

Very often, however, one system (usually the backup) is instrumented to show serviceability to the crew. If a maintenance check is performed on the other (i.e., the primary) the crew can be assured that it is serviceable. In the case of failure, then, they already have a positive indication, through the instrumentation, that the backup system is available and useable. The purpose for this arrangement is to strike a balance between how much instrumentation is used and how much maintenance is required to ensure system serviceability. In some cases, the backup system is automatically switched into service when the primary system fails. Flight crew needs during the flight are primary concerns in making such decisions.

Another common concept used in aviation is the *line replaceable unit* (LRU). An LRU is a component or system that has been designed in such a manner that the parts that most commonly fail can be quickly removed and replaced on the vehicle. This allows the vehicle to be returned to scheduled service without undue delay for maintenance. The failed part, then, can either be discarded or repaired in the shop as necessary without further delaying the flight.

The third concept for minimizing delays for maintenance in aviation is known as the *minimum equipment list* (MEL). This list allows a vehicle to be dispatched into service with certain items inoperative provided that the loss of function does not affect the safety and operation of the flight. These items are carefully determined by the manufacturer and sanctioned by the regulatory authority during the early stages of vehicle design and test. The manufacturer issues a *master minimum equipment list* (MMEL) which includes all equipment and accessories available for the aircraft model. The airline then tailors the document to its own configuration to produce the MEL (more on this in Chap. 5). Many of these MEL items are associated with redundant systems. The concept of the MEL allows deferral of maintenance without upsetting the mission requirements. The maintenance, however, must be performed within certain prescribed periods, commonly 1, 3, 10, or 30 days, depending on the operational requirements for the system.

The items are identified in the MMEL by flight crew personnel during the latter stages of new aircraft development. Thus, flight personnel determine what systems they can safely fly the mission without or in a degraded condition.

These flight crew personnel also determine how long (1, 3, 10, or 30 days) they can tolerate this condition. Although this is determined in general terms prior to delivering the airplane, the flight crew on board makes the final decision based on actual conditions at the time of dispatch. The pilot in command (PIC) can, based on existing circumstances, decide not to dispatch until repairs are made or can elect to defer maintenance per the airline's MEL. Maintenance must abide by that decision.

Associated with the MEL is a *dispatch deviation guide* (DDG) that contains instructions for the line maintenance crew when the deviation requires some maintenance action that is not necessarily obvious to the mechanic. A dispatch deviation guide is published by the airplane manufacturer to instruct the mechanic on these deviations. The DDG contains such information as tying up cables and capping connectors from removed units, opening and placarding circuit breakers to prevent inadvertent power-up of certain equipment during flight, and any other maintenance action that needs to be taken for precautionary reasons. Similar to the MEL is a *configuration deviation list* (CDL). This list provides information on dispatch of the airplane in the event that certain panels are missing or when other configuration differences not affecting safety are noted. The nonessential equipment and furnishing (NEF) items list contains the most commonly deferred items that do not affect airworthiness or safety of the flight of the aircraft. This is also a part of the MEL system.

Although failures on these complex aircraft can occur at random and can come at inopportune times, these three management actions—redundancy of design, line replaceable units, and minimum dispatch requirements—can help to smooth out the workload and reduce service interruptions.

Establishing a Maintenance Program

Although there has been a considerable amount of improvement in the quality and reliability of components and systems, as well as in materials and procedures, over the 100-year life of aviation, we still have not reached total perfection. Aviation equipment, no matter how good or how reliable, still needs attention from time to time.

Scheduled maintenance and servicing are needed to ensure the designed-in level of perfection (reliability). Due to the nature of the real world, some of these components and systems will, sooner or later, deteriorate beyond a tolerable level or will fail completely. In other instances, users, operators, or even maintenance people who interface with these components and systems can misuse or even abuse the equipment to the extent of damage or deterioration that will require the need for some sort of maintenance action.

We have seen that components and systems fail in different ways and at different rates. This results in a requirement for unscheduled maintenance that is somewhat erratic and uncertain. There are often waves of work and no-work periods that need to be managed to smooth out the workload and stabilize the manpower requirements.

Those components exhibiting life limits or measurable wear-out characteristics can be part of a systematic, scheduled maintenance program. Design redundancy, line replaceable units, and minimum dispatch requirements have been established as management efforts to smooth out maintenance workload. But there are numerous components and systems on an aircraft that do not lend themselves to such adjustment for convenience. Occasionally, inspections and/or modifications of equipment are dictated—within specified time limits—by aviation regulators as well as by manufacturers. It is necessary, then, that the maintenance and engineering organization of an airline be prepared to address the maintenance of aircraft and aircraft systems with a well-thought-out and well-executed program. The remainder of this textbook will address the multi-faceted process known as aircraft maintenance and engineering.

The program discussed herein has been created over the years by concentrated and integrated efforts by pilots, airlines, maintenance people, manufacturers, component and system suppliers, regulatory authorities, and professional and business organizations within the aviation industry. Not every airline will need to be organized and operated in the same manner or style, but the programs and activities discussed in this text will apply to all operators.